Effects of Sediment Loading on Primary Productivity and *Brachycentridae* Survival in a Third-Order Stream in Montana

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Abstract

Sedimentation has been acknowledged as one of the most damaging and widespread sources of pollution throughout the United States, and the majority of it is the result of agriculture and development processes (Waters 1995). In order to examine the possible effects of sedimentation resulting from agricultural processes, which are a large source of income throughout the United States, twelve in-stream experimental channels were set up in Mission Creek in northwestern Montana. In the channels, a high sediment treatment and a low sediment treatment were used to examine the effects of sedimentation on periphyton growth and *Brachycentridae* survival. Significant effects of treatment were found on periphyton growth but not on *Brachycentridae* survival. This experiment suggests that increasing sedimentation in the Mission Valley region could have serious effects on primary productivity in streams, and subsequently influence economic interests such as agriculture, tourism, and recreation.

Introduction

Sedimentation has been recognized as one of the most damaging and prevalent sources of pollution in streams in North America (Waters 1995). It can result from point source discharges such as mining and construction processes, non-point sources such as runoff from agriculture and forestry, and from bank erosion (Suren and Jowett 2001). Increases in fine sediment loads in streams have been found to lead to increased turbidity and decreased light penetration, changes in stream flow, decreased organic matter ratios in periphyton, and increased sediment deposition (Suren and Jowett 2001; Quinn et al. 1992; Hicks and Griffith 1992; Graham 1990; Wood and Armitage 1997). These changes can cause substantial alterations in substrate composition and structure, as well as have wide-reaching effects on local food webs (Suren and Jowett 2001).

In addition to influencing the physical and chemical characteristics of a stream, sedimentation has also been shown to have strong effects on periphyton composition and growth and invertebrate behavior and abundance. Sedimentation provides additional sources of nutrients, often leading to excessive plant growth, and higher sediment deposition can lead to increased levels of non-living periphyton in addition to causing significant changes in periphyton community composition (Yamada and Nakamura 2002; Schofield et al. 2004). Furthermore, sedimentation can directly result in higher drift of invertebrates or decreases in macroinvertebrate abundance (Suren and Jowett 2001; Connolly and Pearson

2007). Macroinvertebrates of many taxa have also been shown to actively avoid habitats with elevated sedimentation levels, demonstrating behavioral responses to this physical change (Connolly and Pearson 2007).

In Western Montana, as in many areas in United States and around the world, the main sources of sediment loading on rivers and streams are agriculture and development. In the past decade the acreage of land cultivated has increased due to attempts to promote ethanol and other biofuels in addition to maintaining adequate food supplies. This elevated demand for agricultural processes is likely to keep rising with the growing world population and dwindling fuel supply, and it is expected that agriculture will continue to contribute large amounts of sediment to waterways.

In this experiment, I examined the effects of different amounts of elevated sediment loads on periphyton growth patterns and invertebrate survival and distribution. Based on previous studies, I chose to use *Brachycentridae* in the order Trichoptera as the invertebrate indicator. Ryder (1989) showed that increased suspended sediment could cause filter feeders to ingest more inorganic silt, with subsequent negative effects on growth and nutrition. *Brachycentridae* is a common filter-feeding species in my study area that has a low stress tolerance and high response to pollution levels, making them good indicators of any relevant changes in the stream (Voshell 2002). Periphyton biomass levels on artificial substrates taken over time in the channels were used to determine changes in periphyton growth patterns. I hypothesized that higher amounts of sediment loads would result in (1) increased periphyton biomass, due to higher nutrient availability associated with the sediment treatments; and (2) decreased *Brachycentride* survival rates as a result of inability to drift to more suitable habitats and due to poor quality food with lower organic to inorganic ratios in the periphyton community for filtering.

Methods

Study Area

This study took place in Mission Creek on the National Bison Range in northwest Montana. At the sampling site, Mission Creek is a third-order stream located approximately fourteen kilometers downstream of Mission Reservoir, a man-made dam created for irrigation purposes. Mission Creek has multiple agricultural channels running into it upstream of the National Bison Range (GPS: 47º21'39.75"N, 114º10'42.80"W; Elevation: 900 m). The stream flows westerly along the northern edge of the National Bison Range, flowing into the Flathead River roughly ten kilometers downstream. The study was conducted in a pool approximately ten meters wide, and the average current at the end of the study period ranged from 1.19±0.20 to 1.50±0.48 m/s. The substrate was mostly cobble.

Trichoptera: Brachycentridae

The *Brachycentridae* family is distributed throughout North America and is composed of five genera and thirty-six species. *Brachycentridae* living in larger streams, such as Mission Creek, attach to the dorsal surfaces of stones, where they feed by filtering particles of organic matter from the flowing water with long hairs on their back legs (Voshell 2002). *Brachycentrus americanus* and *Brachycentrus occidentalus* overwinter in cases made of thin pieces of vegetation in a log cabin form. Since *B. occidentalus* emerge in mid-June, it is believed that the species used for this study were *B. americanus*, as they emerge as adults in August and

September in this region of Montana (Hauer and Stanford 1986). All *Brachycentridae* used were found within ten meters of the study site. They are the dominant *Trichoptera* in the area, along with the families *Helicopsychidae* and *Uenoidae*. They also have very low stress tolerances, making them good indicators of changing pollution levels (Voshell 2002).

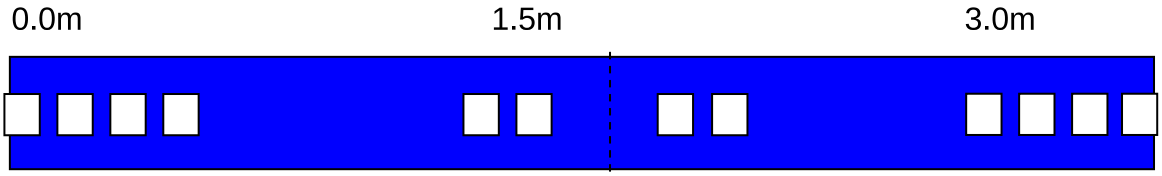
Experimental design

To examine the effects of increased sediment loads on periphyton growth and *Brachycentridae* survival, twelve in-stream channels were created. These served as four replicates of three channel treatments. Treatments consisted of high sediment addition, low sediment addition, and no sediment addition. Each channel was made using a piece of clear plastic (dimensions ≈ 3.6m long), which was folded in half to create streams 0.15 ± 0.3m wide by 0.08 ± 0.025m deep, resulting in each channel containing approximately 56.6 liters of water at any given time. Insect screening was affixed to the front and back ends of each channel to contain the *Brachycentridae* within the experimental channels. Channels were set in a randomized block arrangement, with each of the four blocks containing a random arrangement of the three treatments. Channels were checked twice a day, once in the early morning (730 ± 0.5h) and once in the evening (1600 ± 2h), and all screening was cleared to promote water flow. Channel heights within the water column were also adjusted to maintain a consistent depth and volume at these times. Cobble from the surrounding stream was scrubbed of any invertebrates, baked at 450ºF for 1h and then placed in the channels to create a more natural environment for the invertebrates. The study ran for seventeen days, from July 15 to July 31, 2008.

Based on previous work done in the Mission Valley indicating that the sediment load in agricultural irrigation ditches was approximately 260 mg/L (Alldred 2007), the amount of sediment added for high sediment treatments was determined to be 600 mg/L and for low sediment treatments to be 300 mg/L. All sediment used was gathered from directly downstream of the study site prior to the beginning of the experiment, dried, sifted, and baked at 60ºF for 3h prior to use. Proper sediment treatments were created by placing a 34-gram or 17-gram sediment cake in a mesh bag at the head of each channel at 730 ± 0.5h every day, with the amount of sediment in grams being calculated from the volume of water in the channel at any one time. The use of the cake and the bag were to allow the sediment to diffuse into the channel over time in order to better approximate natural sediment influxes. During the evening visit, all bags were palpitated to release any remaining fine sediment and then turned inside out to allow the release of any larger sediment particles throughout the night.

Periphyton growth was measured by placing twelve 0.01 m^2 unglazed white ceramic tiles in each channel. In previous studies, these tiles have been shown to accumulate periphyton in a manner similar to natural substrata

(Lamberti and Resh 1985). Four tiles were placed in each section, with a front, middle, and back section as seen in the diagram below.



All tiles were soaked in a closed container of stream water for five days to leach any chemicals, and were then microwaved for sterilization. Although all tiles were initially attached to the channels, some tiles did come loose during the course of the experiment and flipped over or drifted down the channels. These tiles were carefully put back in place as soon as possible and all tile flips were recorded as a raw count of number of times flipped per individual tile.

On days 4, 8, 12, and 16 one tile from each section of each channel was randomly selected and removed for periphyton measurements. All attempts to pick off any filamentous algae on top of the sediment on the tiles were done prior to rinsing the sediment off the tiles. The filamentous algae was then combined with any algae scraped off the tiles and filtered through a pre-dried, pre-weighed coffee filter. These filters were subsequently dried at 60ºF for 24 hours and reweighed to determine dried periphyton biomass using the following formula:

$$DM = (W_a – W_f)/A_t$$

where W_a = dried algae on filter in grams, W_f = predried filter in grams, and A_t = area of tile in square centimeters (Hauer and Lamberti 2006).

In order to examine the effects of sediment levels on *Brachycentridae* species survival, twenty-five Brachycentrids were collected from rocks in the surrounding stream and placed at the front of each channel on Day 1 of the experiment. Care was taken to disturb the Brachycentrids as little as possible during the moving process. On Day 17, the total number of living Brachycentrids in each channel were counted and recorded, as well as their location and the number of dead Brachycentrids found.

Temperature, dissolved oxygen, conductivity, and pH were measured in the back of each channel and in the stream directly in front of the experimental area every four days. Nitrate, ammonia, and phosphate were also measured in each experimental stream at these times. Temperature, dissolved oxygen, and conductivity were measured with a YSI Model 85 handheld meter, and pH was measured using a Hanna pH meter. Nitrate, ammonia, and phosphate were measured using a DR/890 HACH® Colorimeter set.

SYSTAT 10.0 was used to analyze all data. Physical, chemical, periphyton and *Brachycentridae* survival data were analyzed using repeated measures general linear models. A Kruskal-Wallis test was used to analyze *Brachycentridae* recovery by section due to non-normality of the data. Relationships between primary productivity, *Brachycentridae* survival, and physical and chemical factors were analyzed using linear regressions.

Results

Four physical characteristics, pH, temperature, dissolved oxygen, and conductivity, were measured in each channels on days 2, 6, 10, and 14. Each characteristic was also measured in the stream directly in front of the experimental setup during each sampling period. Flow was also measured in each block on day 17 only, with no difference between blocks (Fig. 1). Among the other physical characteristics, only pH was found to be significant by treatment, showing decreasing pH with higher sediment addition. pH was also significant by round with an increase on the second round, followed by a slight decrease in the third round and a large increase in the fourth round (Table 1; Fig. 2a). Temperature, dissolved oxygen, and conductivity were all significant by round but not by treatment (Table 1; Fig. 2b-d). Temperature and conductivity both went up in the second and third rounds and then fell to a level similar to their first measurements in round four. Dissolved oxygen stayed fairly constant except for round three, although there may have been a problem with the dissolved oxygen meter during this round. This possible discrepancy was kept in mind when doing other comparisons.

Nitrate, phosphate, and ammonia were all measured over time in four rounds as well. Due to numerous ammonia levels below the detection level (less than 15% of samples were non-zero), ammonia was determined to be negligible and was not included in any further analyses. Nitrate was found to be significant by round but not by treatment, with a slight increase in control and high in round four (Table 2; Fig. 3a). Phosphate was not significant by round or treatment (Table 2; Fig. 3b).

Primary productivity approached significance by treatment and was significant by round, with a large increase in all treatments in round four (Table 3; Fig. 4a). There was a large algal bloom on day 13 that may have influenced all primary productivity results towards an exponential growth pattern, but it is clear that the high sediment treatment showed a greater increase of periphyton on day 16 than the low or control treatments. There was no significant effect of block on primary productivity (Table 4; Fig. 4b).

All treatments showed low rates of *Brachycentridae* survival and no trends or significant differences were found between treatments (Table 5; Fig. 5a). There was no difference or trends in survival by block, although block four seemed to have a higher survival rate than the other blocks (Table 6; Fig. 5b). Due to a lack of normality in the data, a Kruskal-Wallis test was used to test for *Brachycentridae* recovery by section. This included all Brachycentrids found, regardless of condition. No significance was found, although the low treatment was approaching significance and there appeared to be an overall trend to have a higher recovery rate in the net section (Fig. 6).

Linear regressions were used to test relationships between primary productivity, *Brachycentridae* survival, and physical and chemical factors. There was a significant positive linear relationship between pH and primary productivity across treatments, although it was not significantly different by treatment (Table 7; Fig. 7a). In dissolved oxygen, a significant negative linear relationship was only found in the low treatment, and there was no significant different by treatment (Table 8; Fig. 7b).

High and control treatments had a significant positive linear relationship between nitrate and primary productivity, although there was no significant effect of treatment (Table 9; Fig. 8). No linear relationships were found between *Brachycentridae* survival rates and primary productivity levels. There was also no significant effect of treatment (Table 10; Fig. 9).

Discussion

In this experiment, the effects of elevated sediment loads on primary productivity and invertebrate survival were examined as indicators of larger possible effects of sedimentation on overall stream health. The data rejected the first null hypothesis, indicating that different sediment treatments have different effects on periphyton growth. The data failed to reject the second null hypothesis, however, with no significant differences found between treatments on *Brachycentridae* survival.

In examining the primary productivity results, it is interesting to note that the high treatment responded differently in the fourth round of sampling than the low treatment or control channels did and that this difference was only found in the fourth round. This may be due to higher nutrient availability since the treatment inputs may have contained nitrogen, leading to higher concentrations of nitrate in the higher sediment channels. Streams are frequently nitrogen-limited, and since higher nitrate levels were associated with more growth in this experiment, this is likely the case in Mission Creek (Holmes et al. 1996). If Mission Creek is indeed nitrogen-limited, the additional sediment added to the high treatment channels may have been providing enough additional nitrate to provoke such a change in primary productivity.

These differences in round four could also be due to the different types of periphyton that were colonizing the tiles. At the beginning of the experiment, the tiles were being colonized mostly by diatoms, which have relatively small biomass. Since diatom biomass is so small, any treatment effects would have to be very substantial to be able to be detected. Between round three and round four, an algal bloom took place in all channels and filamentous algae began to appear throughout the experiment. These algae had much more biomass per individual, meaning that smaller treatment effects could be detected much more easily. In addition, this shift from diatoms to filamentous algae could have still been occurring, with the high treatment channels being farther along in this transition than the low treatment and control channels. If this experiment had run for a longer amount of time, it would be expected that the low treatment and control channels would have each had significant increases in periphyton dry mass in subsequent rounds, with the low treatment channels showing this increase first.

Other important things to note concerning primary productivity include its relationship with pH and dissolved oxygen. Although it may appear that pH levels are dictating primary productivity based on the strong positive linear relationship between pH and primary productivity, primary productivity was also shown to be increasing exponentially while pH was not, signifying that they are not causing each other. Additionally, there is a strong parallel between changes in stream measurements to changes in channel pH levels over time in all treatments, demonstrating that pH was likely being changed by an outside influence that was affecting all channels in a similar manner. The relationship between dissolved oxygen and primary productivity was also interesting, because higher dissolved oxygen levels were associated with lower primary productivity. This is likely due to higher decomposition rates by bacteria in areas of higher primary productivity, which would use up substantial amounts of available dissolved oxygen for use in the decomposition process.

Brachycentridae survival and dispersion were not found to be significantly related to treatment This was somewhat surprising because survival was expected to mainly be influenced by primary productivity levels, which were found to be affected by different sediment treatments. However, this discrepancy could be due to the fact that primary productivity was only significant in the last sampling period and there then may not have been sufficient time or large enough differences between treatments to see the corresponding effects in *Brachycentridae* survival rates. Additionally, the shift from diatoms to filamentous algae in all channels could have negatively influenced *Brachycentridae* survival, causing a decrease in rates regardless of treatment (Cattaneo and Amireault 1992). It is also important to note that mean primary productivity was used to compare with *Brachycentridae* survival, as survival was only measured at the end of the experiment. By averaging the growth rates of all four rounds for each channel and only taking survival records once, any trends in survival over time were unavailable for analysis. Nevertheless, it was still possible to see the trend of higher *Brachycentridae* recovery in the net section, which reinforces the theory that invertebrates will have increased drift rates in response to habitat changes (Suren and Jowett 2001).

Other possible factors that may have influenced *Brachycentridae* survival rates and lack of treatment effects include differences in flow in all of the channels from the stream, high sediment deposition, the short duration of the experiment relative to *Brachycentridae* life span, and possible balancing effects of higher sediment levels and higher periphyton availability. The flow in the channels may have simply not been fast enough for adequate food collecting, which would have been a problem for Brachycentrids in all channels since there was not a significant difference between blocks in flow rates. The decrease in flow also led to very high rates of sediment deposition in all channels, which may have been too high for the Brachycentrids to be able to filter. Another reason treatment effects may not have been seen is that the length of the experiment was either too long to see the differing effects or too short to really influence the amount of energy the Brachycentrids had to devote to food collection. Finally, the channels with higher sediment rates also had higher periphyton availability, meaning that the positive effects of more available periphyton for food could have balanced the negative effects of more sediment to filter through.

This study suggests that increasing sediment loads could lead to substantial changes in stream composition, with effects on many trophic levels. This is very important because the Mission Valley, along with many other areas throughout the United States, are economically dependent on stream health for agriculture, tourism, and recreation. By increasing sedimentation in the Mission Valley, all of these sources of local income could be considerably affected. Additionally, the effects of increasing sedimentation will be aggregated for those downstream within the valley. Steps should be taken now to control sedimentation throughout the valley in order to maintain stream composition and the economic viability of the Mission Valley’s three largest income sources.

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Tables

Table 1. Physical data by treatment over time using general linear models.

Characteristic	*Source*	*df*	*F*	*P*
pH	Treatment	3	16.782	0.001
	Round	3	1529.058	0.000
	Round*Treatment	9	7.645	0.000
Temperature	Treatment	3	2.610	0.124
	Round	3	96.716	0.000
	Round*Treatment	9	4.493	0.002
Dissolved Oxygen	Treatment	3	0.684	0.586
	Round	3	31.249	0.000
	Round*Treatment	9	1.535	0.192
Conductivity	Treatment	3	2.611	0.124
	Round	3	136.589	0.000
	Round*Treatment	9	1.215	0.331

Table 2. Chemical data by treatment over time using general linear models.

Characteristic	*Source*	*df*	*F*	*P*
Nitrate	Treatment	2	0.718	0.517
	Round	3	8.768	0.000
	Round*Treatment	6	4.363	0.004
Phosphate	Treatment	2	1.141	0.367
	Round	3	0.847	0.482
	Round*Treatment	6	1.174	0.353

Table 3. Primary productivity by treatment over time using a general linear model.

Source	*df*	*F*	*P*
Treatment	4	2.808	0.074
Round	3	124.204	0.000
Round*Treatment	12	1.730	0.101

Table 4. Primary productivity by block over time using a general linear model.

Source	*df*	*F*	*P*
Block(Location)	6	0.528	0.776
Round	3	118.081	0.000
Round*Block	18	1.786	0.078

Table 5. *Brachycentridae* survival by treatment using a general linear model.

Dependent Variable: Percent Alive

N: 11 Multiple R: 0.205 Squared Multiple R = 0.042

Source	*df*	*F*	*P*
Treatment	2	0.175	0.842

Table 6. *Brachycentridae* survival by block using a general linear model.

Dependent Variable: Percent Alive

N: 11 Multiple R: 0.659 Squared Multiple R = 0.435

Source	*df*	*F*	*P*
Treatment	3	1.794	0.236

Table 7. Linear regression of pH and primary productivity across treatments.

Treatment: *Control*

Dependent Variable: Average Primary Productivity

N: 12 Multiple R: 0.722 Squared Multiple R = 0.521

Effect	*Coefficient*	*Std. Error*	*P*
Constant	-15.771	4.444	0.005
pH	1.575	0.478	0.008
Source	*df*	*F*	*P*
Regression	1	10.865	0.008

Treatment: *Low*

Dependent Variable: Average Primary Productivity

N: 16 Multiple R: 0.592 Squared Multiple R = 0.351

Effect	*Coefficient*	*Std. Error*	*P*
Constant	-15.880	5.404	0.011
pH	1.597	0.581	0.016
Source	*df*	*F*	*P*
Regression	1	7.566	0.016

Treatment: *High*

Dependent Variable: Average Primary Productivity

N: 16 Multiple R: 0.748 Squared Multiple R = 0.559

Effect	*Coefficient*	*Std. Error*	*P*
Constant	-20.230	4.566	0.001
pH	2.068	0.491	0.001
Source	*df*	*F*	*P*
Regression	1	17.763	0.001

Table 8. Linear regression of dissolved oxygen and primary productivity across treatments.

Treatment: *Control*
Dependent Variable: Average Primary Productivity
N: 12 Multiple R: 0.490 Squared Multiple R = 0.240

Effect	*Coefficient*	*Std. Error*	*P*
Constant	1.895	1.709	0.294
Dissolved Oxygen	-0.308	0.173	0.106
Source	*df*	*F*	*P*
Regression	1	3.158	0.106

Treatment: *Low*
Dependent Variable: Average Primary Productivity
N: 16 Multiple R: 0.636 Squared Multiple R = 0.404

Effect	*Coefficient*	*Std. Error*	*P*
Constant	3.797	1.570	0.030
Dissolved Oxygen	-0.484	0.157	0.008
Source	*df*	*F*	*P*
Regression	1	9.505	0.008

Treatment: *High*
Dependent Variable: Average Primary Productivity
N: 16 Multiple R: 0.092 Squared Multiple R = 0.008

Effect	*Coefficient*	*Std. Error*	*P*
Constant	-0.478	1.507	0.756
Dissolved Oxygen	-0.050	0.145	0.735
Source	*df*	*F*	*P*
Regression	1	0.119	0.735

Table 9. Linear regression of nitrate and primary productivity across treatments.

Treatment: *Control*
Dependent Variable: Average Primary Productivity
N: 12 Multiple R: 0.656 Squared Multiple R = 0.430

Effect	*Coefficient*	*Std. Error*	*P*
Constant	-1.845	0.298	0.000
Nitrate	2.324	0.846	0.021
Source	*df*	*F*	*P*
Regression	1	7.553	0.021

Treatment: *Low*
Dependent Variable: Average Primary Productivity
N: 16 Multiple R: 0.346 Squared Multiple R = 0.120

Effect	*Coefficient*	*Std. Error*	*P*
Constant	-0.387	0.492	0.445
Nitrate	-1.847	1.337	0.189
Source	*df*	*F*	*P*
Regression	1	1.909	0.189

Treatment: *High*
Dependent Variable: Average Primary Productivity
N: 16 Multiple R: 0.699 Squared Multiple R = 0.489

Effect	*Coefficient*	*Std. Error*	*P*
Constant	-2.018	0.315	0.000
Nitrate	2.779	0.760	0.003
Source	*df*	*F*	*P*
Regression	1	13.372	0.003

Table 10. Linear regression of *Brachycentridae* survival and primary productivity across treatments.

Treatment: *Control*
Dependent Variable: Percent Alive
N: 3 Multiple R: 0.984 Squared Multiple R = 0.969

Effect	*Coefficient*	*Std. Error*	*P*
Constant	0.605	0.093	0.097
Mean Primary Productivity	0.392	0.070	0.113
Source	*df*	*F*	*P*
Regression	1	31.062	0.113

Treatment: *Low*
Dependent Variable: Percent Alive
N: 4 Multiple R: 0.908 Squared Multiple R = 0.825

Effect	*Coefficient*	*Std. Error*	*P*
Constant	-0.532	0.232	0.149
Mean Primary Productivity	-0.636	0.207	0.092
Source	*df*	*F*	*P*
Regression	1	9.427	0.092

Treatment: *High*
Dependent Variable: Percent Alive
N: 3 Multiple R: 0.789 Squared Multiple R = 0.622

Effect	*Coefficient*	*Std. Error*	*P*
Constant	-0.431	0.301	0.288
Mean Primary Productivity	-0.573	0.316	0.211
Source	*df*	*F*	*P*
Regression	1	3.292	0.211

Figures

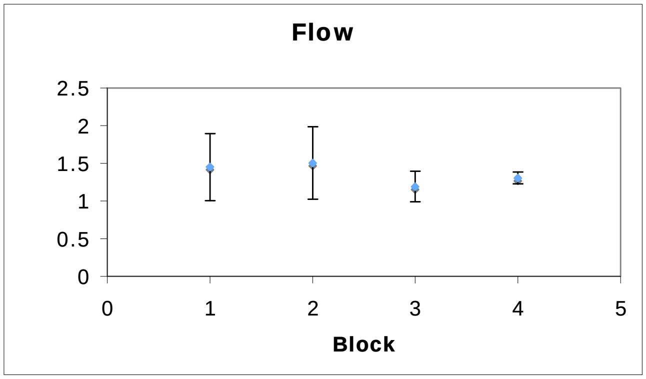

Figure 1. Flow across blocks on Day 17 was not significant (p = 0.510, R^2 = 0.407).

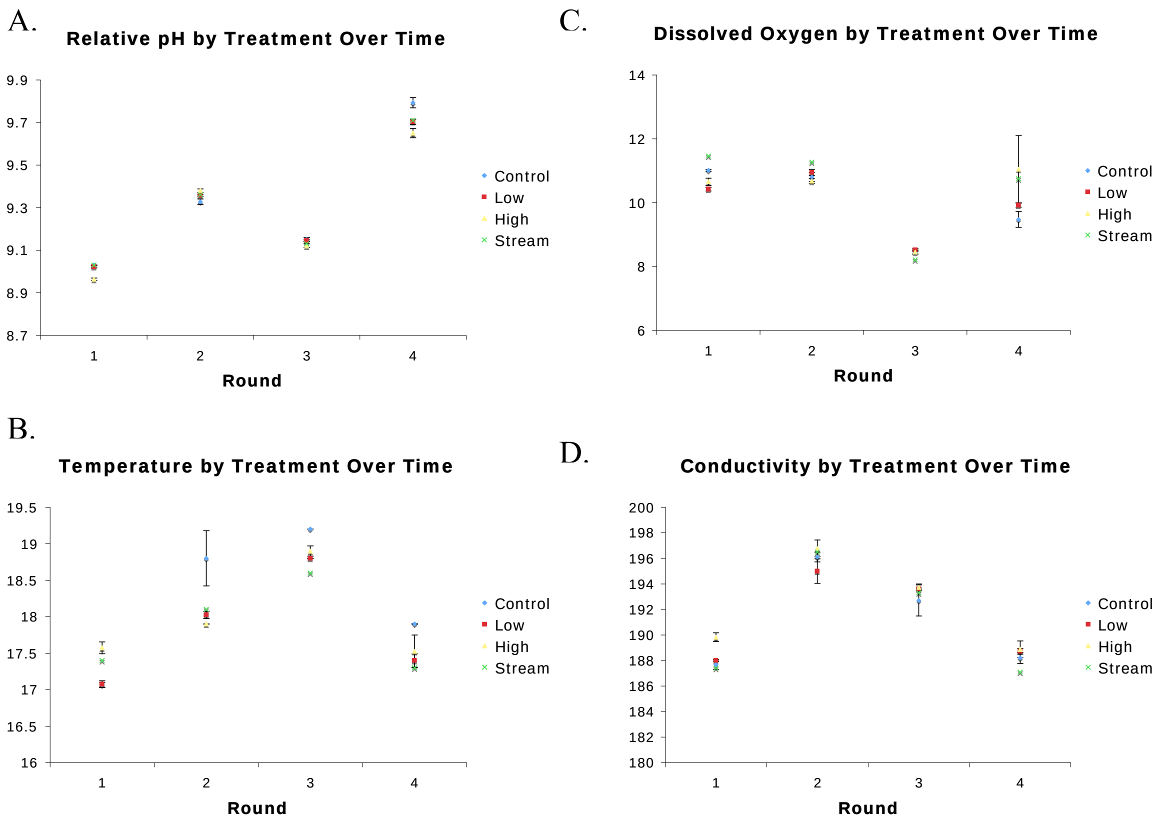

Figure 2. Physical characteristics over time. pH was found to be significant over time for treatment and round ($p_{treatment} = 0.001$, $p_{round} < 0.001$). Temperature was not significant by treatment ($p_{treatment} = 0.124$, $p_{round} < 0.001$), and neither was dissolved oxygen ($p_{treatment} = 0.586$, $p_{round} < 0.001$) or conductivity ($p_{treatment} = 0.123$, $p_{round} < 0.001$). All were significant by round.

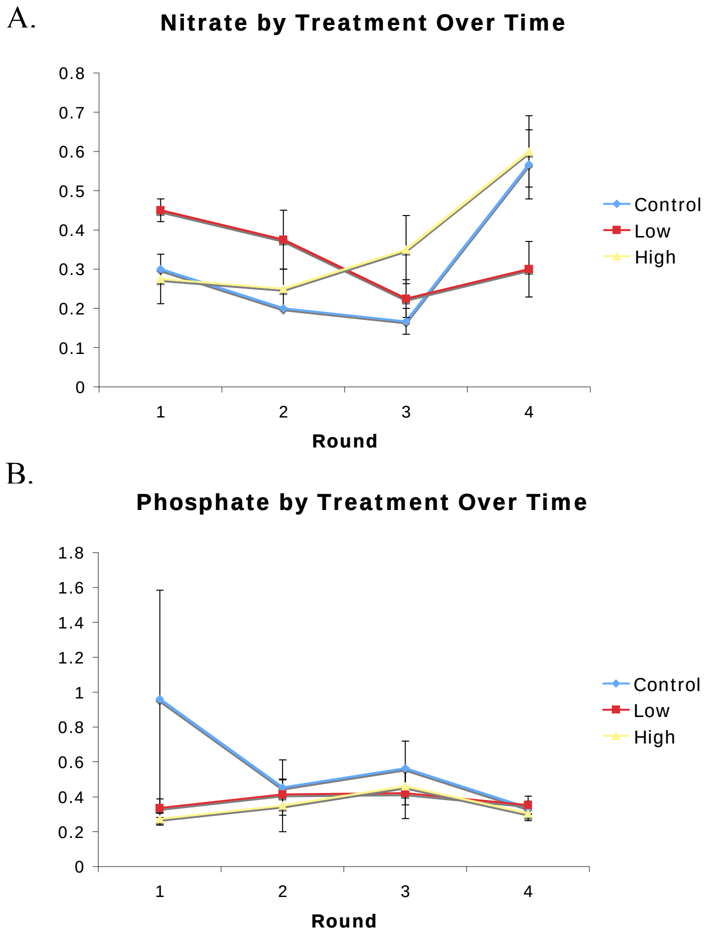

Figure 3. Chemical characteristics over time. Nitrate was significant by round but not treatment ($p_{treatment} = 0.517$, $p_{round} < 0.001$). Phosphate was not significant by treatment or round ($p_{treatment} = 0.367$, $p_{round} = 482$).

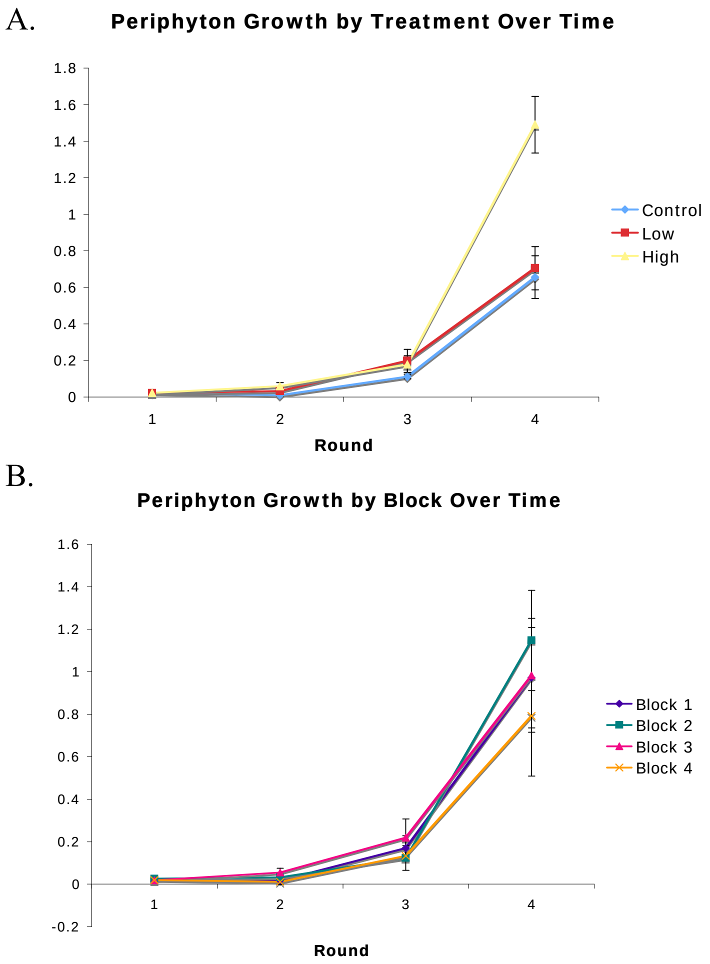

Figure 4. Primary productivity as measured by mean periphyton dry mass over time. Primary productivity by treatment approached significance ($p_{treatment} = 0.074$, $p_{round} < 0.001$). There was no significant difference by treatments between blocks ($p_{treatment} = 0.776$, $p_{round} < 0.001$)

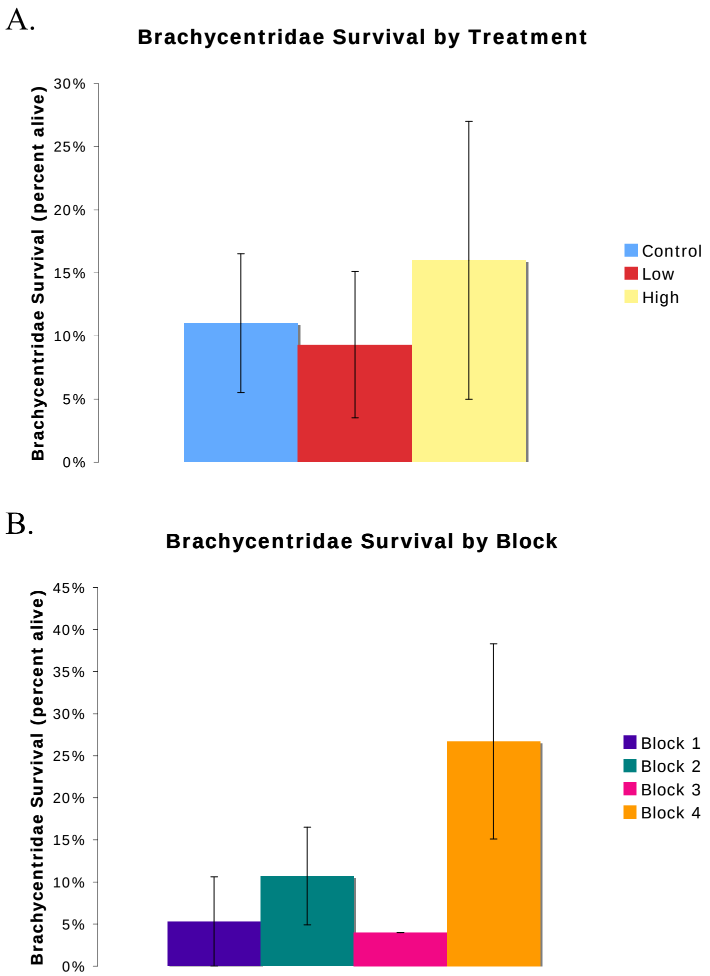

Figure 5. *Brachycentridae* survival over time. There was no significant difference in survival between treatments ($p = 0.842$, $R^2 = 0.042$) or blocks ($p = 0.236$, $R^2 = 0.435$).

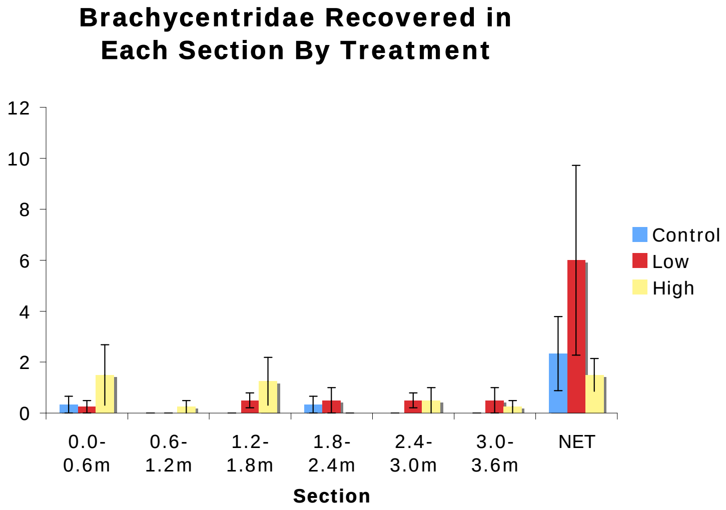

Figure 6. *Brachycentridae* recovery by treatment per section. No significant difference was found between sections in any treatment (Control: p = 0.208; Low: p = 0.063; High: p = 0.371), although there was a strong trend towards higher recovery rates in the net.

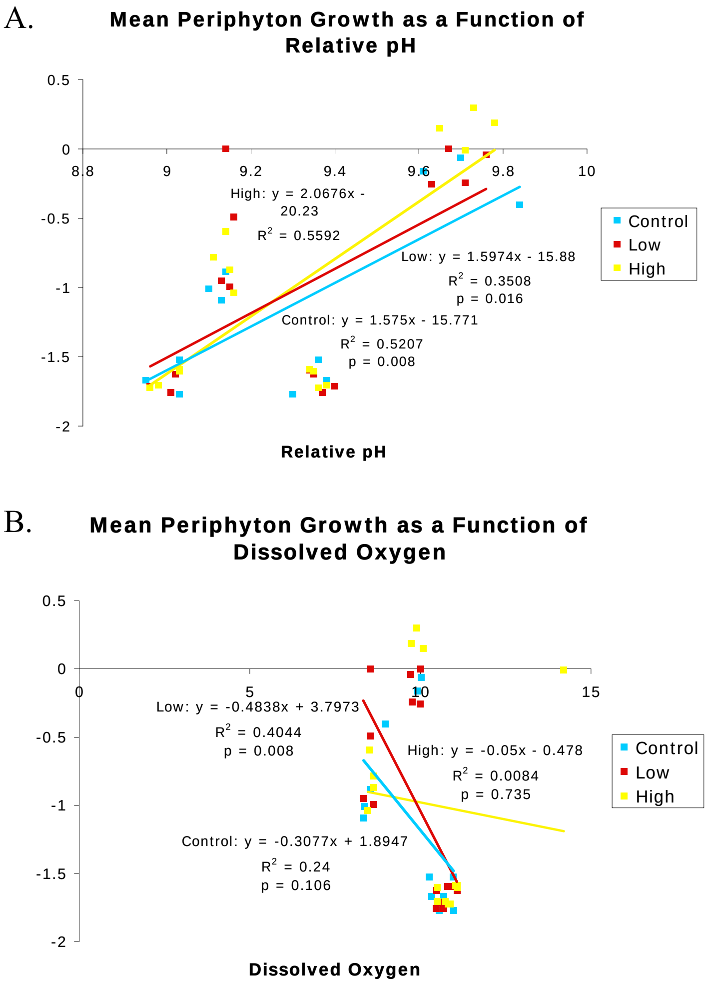

Figure 7. Primary productivity and physical characteristics. There was a significant positive linear relationship between primary productivity and pH, although there was no difference between treatments ($p = 0.822$). There was significant negative linear relationship between primary productivity and dissolved oxygen in the low treatment only, with no significance effect of treatment ($p = 0.685$).

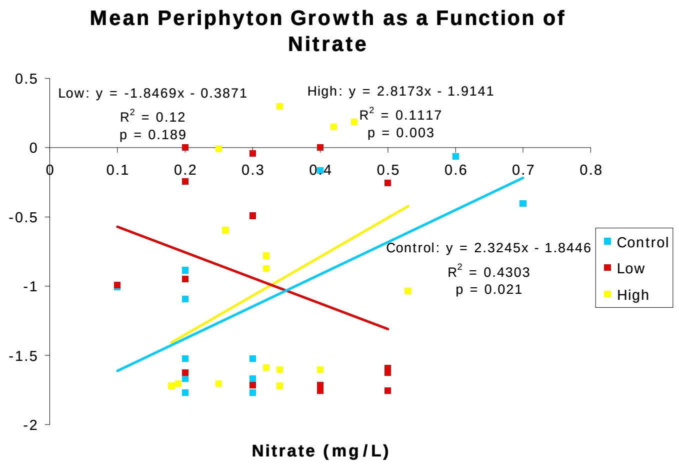

Figure 8. Primary productivity and nitrate. There was a significant positive linear relationship between primary productivity and nitrate in the high and control treatments. No significant effect of treatment on the relationship between primary productivity and nitrate was found ($p = 0.980$).

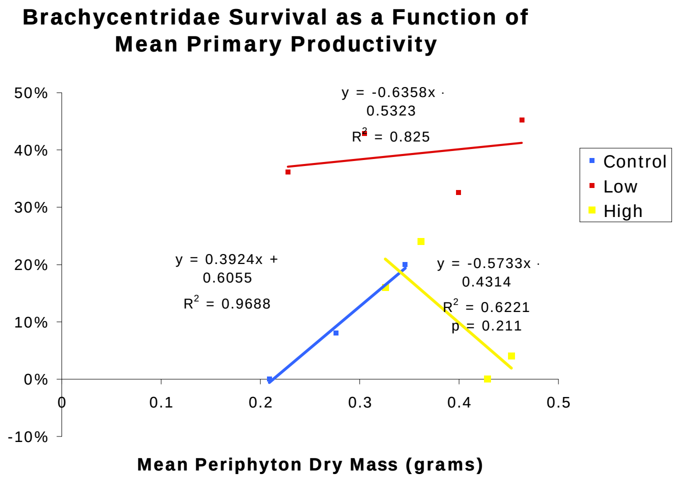

Figure 9. Primary productivity and *Brachycentridae* survival. No significant linear relationships were found between primary productivity and *Brachycentridae* survival rates, and there was no effect of treatment (p = 0.459).